Laboratory Investigations and Numerical Modeling of Loss Mechanisms in Sound Propagation in Sandy Sediments

Brian T. Hefner
Applied Physics Laboratory
University of Washington, Seattle, WA 98105
phone: (206) 616-7558   fax: (206) 543-6785 email: hefner@apl.washington.edu

LONG-TERM GOALS

To develop accurate models for high frequency sound propagation within shallow water sediments.

OBJECTIVES

The scientific objectives are to:

1) quantify the relative importance of scattering and frictional losses in the attenuation of sound in the sediment,

2) evaluate and improve existing models of sound propagation and,

3) develop more complete models of sound propagation which can account for the complexity of shallow water sediments.

APPROACH

The potential loss mechanisms for propagation in sandy sediments will be investigated through numerical modeling, laboratory investigations, and field data analyses. Efforts will be made to determine the relative importance of each of these mechanisms and to use these results to improve existing propagation models or to develop new theories of acoustic propagation through sand sediments.

Laboratory investigations of scatterers in glass bead sediments.

During the Sediment Acoustics Experiment 2004 (SAX04), extensive efforts were made to determine the size distribution, spatial distribution, shape, and composition of shell hash and other objects in the sediment that were larger than the average sand grain size. This data will be used in conjunction with other environmental measurements to model the scattering from, and penetration into the sediment due to volume heterogeneity [1]. This data set coupled with sound speed measurements taken at the site, will also provide an opportunity to study the role of discrete scatterers in sound propagation in the sediment.

Measurements of particle size distribution made during the Sediment Acoustics Experiment 1999 (SAX99) indicated that the shell hash had diameters as large as 10 mm. These pieces have a $ka \approx 3.5$

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14. ABSTRACT
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for a frequency of 200 kHz in the sediment. At these *ka*, Rayleigh scattering is not applicable and a more complicated scattering theory is necessary. In studies of the effects of atmospheric aerosols on the propagation of light, T-matrix formulations have been successful in modeling the scattering of light by distributions of non-spherical particles [2]. These methods will be utilized for the investigations of sediment propagation using the T-matrix formulations developed by Kargl and Lim for single scatterers embedded in Biot media [3].

The models, which will be developed to capture the effects of scattering in sound propagation, will be tested in two ways. The first will be through data-model comparisons of the sound speed and attenuation measurements made during SAX99 and those made during SAX04. During SAX04, propagation measurements will once again be made by a number of different groups to cover a broad range of frequencies at a single site.

The second test of any developed scattering theory will be performed in the laboratory using the glass bead sediments at APL [4]. Previous measurements have determined the sound speed and attenuation in these sediments in the absence of scatterers. By adding scatterers of known size and composition to a known distribution in the glass bead sediment, it will be possible to examine the extrinsic attenuation due to scattering. This is extremely difficult to do *in situ* and the laboratory setting will provide an opportunity to understand the relative importance of both scattering and other mechanisms such as grain-to-grain friction. This is extremely important for the proper determination of any intrinsic parameters which describe intergranular losses such as the models by Buckingham [5] and Chotiros [6].

Numerical grain-to-grain contact modeling.

Because of the highly nonlinear nature of the physics of grain contacts in the sediments, numerical modeling will be used to simulate the individual contact of two grains subjected to an oscillation or impulse comparable to what the grains would experience in the sediment. This work will use techniques which have been developed for lubrication engineering to simulate lubricated contacts of rollers or spheres. Of particular relevance to this work are previous simulations of the collisions of cylindrical rollers or spheres against flat surfaces [7]. These simulations account for viscous flow of the fluid between surfaces, the elastic deformation of the surfaces, the pressure dependence of the viscosity of the fluid, and molecular forces that become important when the film thickness between surfaces become extremely small.

The simulations will initially be used to examine the oscillation of two elastic spheres pressed together in a fluid. This simplified model neglects roughness that would be inherent in a sand grain, but should capture the squeeze flow at the boundaries of the grain contact that is hypothesized to occur during oscillation. This simulation will capture the nonlinear response of the fluid in the small annular gap around the contact area as well as the elastic deformations that occur in the spheres. These results will also be applicable to the more complex rough grain problem such as in Buckingham's model where the dynamics occur at microasperities in the contact region. The simulation of the contact of two spheres should approximate the dynamics of the microasperity contact with the proper scaling. This may provide insight into the parameters used in Buckingham's model and could strengthen the predictive capability of his theory.

Force chain quantification and sound propagation modeling.

To understand the role of the heterogenous nature of the stress distribution in unconsolidated media, efforts will be made to develop models that account for the presence of force chains. These models will attempt to incorporate the force chains into a Biot description of the medium or as scattering centers embedded in the medium. Central to an attempt to model a medium containing these force chains is a statistical description of the force chain distribution. A majority of measurements made by the granular physics community have focused on determining the probability distribution of the forces between the grains. Very little work has been done to statistical describe of the *spatial* distribution of the chains. Describing factors such as the correlation length of these chains, is extremely important in determining the degree to which they will produce scattering in the medium.

Since the development of a proper statistical description of the medium is essential to the propagation modeling, a measurement of the force chain distribution in the medium will be made. During SAX04, sediment cores were collected at the experiment site and CT scans of these cores have been performed by Allan Reed at NRL-Stennis to determine the arrangement of sand particles in the core. These particle distributions will be used to provide data for finite element simulations of the sediment to determine the distribution of the bulk moduli in the medium.

WORK COMPLETED

Progress has been made on the development of a theory which incorporates bulk modulus heterogeneities into Biot theory. This theory has been developed in collaboration with Darrell Jackson at APL-UW. In the model under development, these heterogeneities are assumed to be much smaller than the wavelength of the fast compressional wave and hence should not scatter energy into incoherent fast waves. However, the heterogeneities are on the scale of the slow compressional wave and this should lead to mode conversion of the fast compressional wave into the slow compressional wave. The losses due to mode conversion produce an increase in the attenuation of the fast compressional wave. The initial results of this theory were presented at the meeting of the Acoustical Society of America in Vancouver, BC [8].

Since this is the first year of this program, efforts have largely focused on developing the computational techniques to begin the simulations discussed above. Following SAX04, Allen Reed began to analyze the sediment cores using CT scans. This work has progressed gradually and is nearly to the point where work can begin on FEM simulations. In the meantime, work has begun on molecular dynamics simulations to begin to examine the distribution of force chains in simple sediments composed of spheres with and without friction at the sphere contacts.

RESULTS

There are no new results to report at this time.

IMPACT/APPLICATIONS

This work will potentially lead to the development of physically based models of sound propagation in sandy sediments by examining the details of various proposed loss mechanisms such as grain-to-grain shearing and scattering.

RELATED PROJECTS

1. Title: High-Frequency Sound Interaction in ocean sediments, Grant# N00014-98-1-0040, E.I. Thorsos, PI. http://www.apl.washington.edu/projects/SAX04/summary.html The efforts of SAX04 were coordinated under this program. The determination of shell size distribution in the sediment as well as the measurement of sediment sound speed and attenuation at the SAX04 site was conducted under this program. The results of the analysis of this data will be used in the development of theories of sound propagation.

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